Groundwater on small Adriatic karst islands

Ognjen Bonacci[1] & Tanja Roje-Bonacci[1]

[1]Civil Engineering Faculty, University of Split 21000 Split,
Matice hrvatske St. 15, Croatia; E-mail: obonacci@gradst.hr

Abstract: The paper gives a review of water resources, which exist, on the small Adriatic karst islands. Ghyben-Herzberg relation is discussed in detail. The last part of the paper is dedicated to the island of Brač and the information collected on its karst aquifer.

Key words: groundwater, small island, hydrogeology, Ghyben-Herzberg relation, Croatian karst

Introduction

An island can be defined as a landmass surrounded by the sea and with an area that is small compared to the global land surface. It is hydrological circumscribed unit. Its inflows and outflows are local.

This paper treats small and very small islands. The term small island should apply to islands with areas less than approximately 1,000 km^2 and to larger, elongated, islands where the maximum width of the islands not exceeds 10 km (Falkland, 1991). Very small islands have areas less than 100 km^2 or width no greater than 3 km.

The island's freshwater lens is a dynamic system maintained by precipitation, with a net flow from the aquifer towards the seacoast. Ghyben-Herzberg principle or approximation (Ghyben 1888, Herzberg, 1901) assumes a sharp interface between fresh water (density ρ_f=1000 kg/m^3) and salt sea water (density ρ_s=1025 kg/m^3). According to this approximation fresh water floats on sea water. There is 40 m of fresh water below sea level for every meter of above sea level. The number 40 is the density - difference ratio between sea water and fresh water $(\rho_f/(\rho_s-\rho_f))=40$. This principle treats the fresh groundwater and underlying sea water as hydrostatic, immiscible fluids, what is not appropriate. The interface between fresh and sea water is not sharp. A transition zone of salinity exists. Its depth depends on geology affecting the branching nature of flow paths and on the dynamic changes of flow rates, tides recharges etc.

Geography, climate and water resources of small Adriatic karst islands

There are 1185 islands, ridges and reefs along the Croatian coastal belt of the Adriatic Sea (Figure 1). Their total area amounts 3273.8 km^2. That is 5.3 % of total Croatian land area. Only eight of them have an area greater than 100 km^2 and thirteen larger than 50 km^2. All the islands ridges and reefs expect thirty-odd very small, occur in a belt 500 km long and 80 km wide, running along the Croatian mainland coast.

Scientific paper

Climate is Mediterranean. The average annual air temperatures increase from the North to the South. The average monthly air temperatures on the Northern Adriatic islands varied between 5 to 6 °C (in January and February) and 23 to 25 °C (in July and August) (BONACCI 1991, BONACCI AND MARGETA, 1991).

Figure 1. Map of the Adriatic Sea

The precipitation regime differs significantly from one island to another. The larger and higher islands, as well as those situated closer to the shore, generally have a greater quantity of precipitation than the smaller lower islands, more distant from the shore. The rainfall distribution during the year is similar on all the islands, with the largest quantity in the cold period, from October to March, when about 65 % of annual precipitation falls.

GEOLOGY AND HYDROGEOLOGY

The appearance, circulation and retention of water are primarily governed by the geological composition of the islands. Almost without exception, (only two are volcanic) they are composed of carbonate rocks with dominant deep karst forms. There are also some impermeable rocks and layers, which combined with the prevalent permeable and soluble limestone and dolomites, make possible the appearance and retention of fresh water. The dolomites belong to the Jurassic and Lower Cretaceous period. Limestone and dolomite belong to different periods, thus, their permeability characteristics are completely different, and hence their hydrogeological function. The thickness of carbonate rocks ranges from the order of magnitude of several thousand meters.

The main water-bearing rock is limestone, and sporadically dolomite. There are great varieties between limestone permeability in horizontal and vertical directions. Size of the karst fractures, joints and fissures varies from one island to another. Hydrogeological role of the dolomites is different. Their permeability is much smaller than the permeability of the surrounding limestone. Majority of groundwater is stored in the karst aquifers but there are some smaller aquifers in the nonkarst terrains.

The hydrogeological conditions, especially on the very small islands and in the aquifers along the coast of the largest islands, are such that the contact between the sea water and the fresh groundwater is direct. Accordingly, it happens that after a relatively short pumping time of fresh groundwater, it quickly becomes salty.

Case study of the island of Brač

The island of Brač is situated in the central part of Croatian Adriatic littoral. It is 37 km in length and ranges between 10 and 13 km in width, with an area of 395.4 km^2. Figure 2 presents the map of island with plotted mean annual isohyetal lines (1961-1990) and locations of 13 rainganging stations.
The hydrogeological mapping recorded 287 coastal brackish karst springs and vruljas, three fresh water springs and six sites in which fresh water flows to the surface by dispersion.
The construction of the water supply pipeline required the drilling of the Vidova Gora tunnel, 8,609 m long, with a circular cross-section diameter of 2.35 m (Figure 2). The greatest altitude of the tunnel is at 134.00 m a.s.l. in its middle.

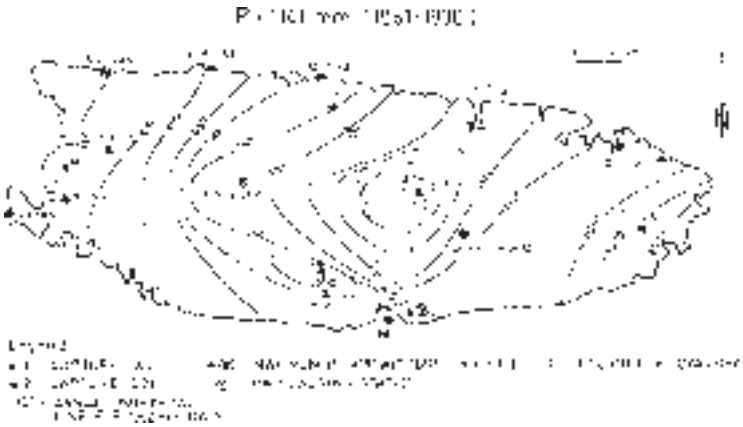

Figure 2. Map of the island of Brač

During the 1950's, numerous hydrological investigations were carried out on the island resulting in two captures: Dol and Bol. The Dol capture in the vicinity of the Postire town, designated as 1 in Figure 2, is still in use, while the Bol town capture, in the vicinity of the Bol town, designated as 2 in Figure 2, has been abandoned due to insufficient water quantities obtained from it. Since the water demand on the island has increased, plans are being made for the re-activation of this capture.
In the wider area around the Dol capture, the influence of seawater level oscillations can be observed at a distance of about 1000 m from the coast, with a delay of 2 to 3 hours and a decrease in the groundwater level oscillations ranging from 6 to 10 cm. Under natural conditions, the groundwater never becomes salty but during the pumping process sea water

invades into the karst aquifer. At a distance of 2,100 m from the coast, which is the location of the Dol capture, the groundwater level ranges from 2.00 m a.s.l. to 11.5 m a.s.l. and the sea water oscillations do not influence the change in the groundwater levels. The natural groundwater salinity (without pumping) ranges from 20 to 40 mg/l, which means that this fresh water can be used for drinking. The sea water inflow and the increased salinity occur at about 500 mg/l during the pumping process in the summer dry periods, when the groundwater level on the location of the Dol capture is below 2.5 m a.s.l.
The Bol capture is constructed as a horizontal gallery, 386 m long, extending in the south-north direction. At the gallery level of 300 m, the flysch barrier gives way to permeable limestone layers in which the karst aquifer has been formed. In order to ensure high-quality fresh water from the Bol capture the existing gallery will have first of all to be made impermeable along the flysch layers so as to prevent the inflow of sea water and infiltrated water from the surface along this section. Subsequently, it will be necessary to excavate horizontal gallery in the east-west direction at least 1000 m long

CONCLUSIONS

Understanding the interaction of groundwater and hydrological cycle on the small karst islands is essential to water managers and water scientists. The paper describes the main hydrological, climatological, geological and hydrogeological characteristics of the small Adriatic karst islands. All types of fresh water exist on them, but the most abundant is groundwater stored in their karst aquifers. The quantities and characteristics of the small Adriatic islands karst aquifers have not been investigated sufficiently until now.
While considering the water resources management on the small Adriatic karst islands and especially their groundwater abstraction, the concept of sustainable management and development should be fully appreciated. The positive circumstance is that ecological systems and the biodiverstiy on the small Croatian Adriatic karst islands are preserved satisfactory. The role of groundwater is essential for the island development and for their ecological system preservation.

REFERENCES

BONACCI, O. (1991) Hydrology and water resources of small karst islands along the Yugoslav Adriatic coast. Krš Jugoslavije -Carsus Iugoslaviae 13: l-34.

BONACCI, O., MARGETA, J. (1991): Case Study No. 12, Silba. In: Falkland A (ed) Hydrology and water resources of small islands: a practicale guide. UNESCO, Paris: 394-400.

Falkland, A. (ed) (1991): Hydrology and water resources of small islands: a practical guide. UNESCO, Paris.

GHYBEN, W. B. (1888): Nota in verband met de voorgenomen putboring nabij Amsterdam (Notes on the probable results of the proposed well drilling near Amsterdam). Inst Ing Tijdschr 21:8-22

HERZBERG, A. (1901): Die Wasserversorgung einiger Nordseebäder. Wasserversorgung 44:815-819 and 84-844.